EXECUTIVE SUMMARY

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EVALUATING THE PERFORMANCE OF THERMOACOUSTIC COOLING

Experimental investigations of an electro-dynamically thermoacoustic cooler prototype were performed. The prototype was designed to provide 130 W (443.6 Btu/hr) cooling for cold air temperatures around 16°C (60°F) and hot air temperatures varying between 24°C and 38°C (75°F and 100°F). The device is approximately one half-wavelength long, and was designed for operation in a 75% helium-25% xenon mixture, at 2.07 MPa (300 psi) and 150 Hz. However, the working fluids used in experimental work have been various mixtures of helium and argon, at operating frequencies near 170 Hz. The prototype used a tuned "moving magnet" electro-mechanical actuator. The thermal performance of the complete system was measured over a range of operating conditions, for varying gas mixtures. Detailed sound pressure and temperature measurements provided information from which the overall efficiency, capacity, and temperature lift of the cooling system were estimated, in addition to the heat exchange coefficients and performance of the heat exchangers.

Net acoustic power inputs of up to 120 W (409.4 Btu/hr) were achieved, with an electro-acoustic transduction efficiency varying between 20% and 50%, reaching values as high as 60% in a few cases. In comparison, the theoretical maximum driver efficiency was estimated to be 67%. The measured cooling capacity varied greatly, and peaked at around 130 W (443.6 Btu/hr) for a temperature lift of 6.7°C (12°F). The acoustic pressure amplitudes were near 3% of the mean pressure in the stack region, and the heat rejected to a secondary fluid reached values up to 250 W (853 Btu/hr). The best relative coefficient of performance achieved was less than 3% of

Carnot, based on the net input acoustic power. The best overall efficiency achieved was thus 1.2% of Carnot. The acoustic power level exceeded the target value for the desired cooling load and the target temperature lifts and efficiencies were not achieved. This was generally attributed to “nuisance” heat loads, acoustic streaming effects, and migration of species within the inhomogeneous mixture. The non-dimensional heat exchanger performance in the thermoacoustic system was found to be only slightly less than that in a steady uniform flow when the root-mean-square particle velocity is used for a velocity scale, and the stack end temperature is used in the calculation of the temperature lift. It was also found that this performance value is better than that predicted by linearized boundary layer models often used in linear acoustic models.

Although the simulation model did not provide very good performance predictions for the Purdue prototype, it is useful for predicting the upper limit to performance in the absence of non-linear effects such as streaming and for comparing alternative designs and operating conditions. In this study, the simulation model was combined with optimization tools in order to identify the most suitable operating temperatures for thermoacoustic cooling and to target applications for further research and development. The optimum operating range for thermoacoustics seems to be for temperature lifts between about 37.8°C and 65.6°C (100°F and 150°F). This could correspond to refrigerator/freezer applications. Thermoacoustic cooling does not seem appropriate for air conditioning applications where temperature lifts are small and could not be readily used for cryogenic cooling.

Future work is needed before a definitive assessment of the potential of thermoacoustic cooling technologies can be made. The discrepancies between the linear thermoacoustic models and experimental data need to be explained. Computational fluid dynamic methods may be used to obtain predictions that account for non-linear effects such as streaming. Experimental procedures must be refined to improve the accuracy of measured heat capacity estimates. This can be done by installing a driver cooling system, and improve the thermal insulation between different system components. Finally, additional data documenting the effects of unexplored system parameters such as the resonance frequency would be useful. The addition of a tunable resonator attached to the cold end of the current prototype would provide the means to vary the operating frequency while maintaining the system at resonance.